International Journal of Computer Science and Software Engineering (IJCSSE), Volume 6, Issue 10, October 2017
ISSN (Online): 2409-4285 www.IJCSSE.org Page: 216-222

Image Processing Based Analysis of the Compressive Strength for the Stones Used In Historical Masonry Structures

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ABSTRACT

Determining the mechanical properties of materials used in masonry structures, which is one of the most important issues in civil engineering, is a field that requires very laborious and intensive laboratory work. As a result of these studies, basic mechanical properties such as compressive strength and tensile strength of structures can be obtained. These parameters, especially used in the restoration process of these structures, are the basic arguments for determining the real behavior of the structure. With this study, it was provided to examine the stones used in the historical masonry structures with computer vision technology. For this purpose, stones having different qualities taken from stone quarries are primarily taken through a camera. Subsequently, the image of each sample is transferred to the computer environment and the properties of these samples are obtained by image processing. After all these tests, these samples are tested in the laboratory and compressive strength are measured. As a result, the data obtained from the laboratory environment and the results obtained by image processing are compared and the calibration of this proposed image processing based analysis method is provided. With this new approach, which is a recommended image processing base, it is possible to perform experimental applications in the laboratory environment in computer environment. Again due to these studies very difficult and lengthy studies have been shortened to a considerable extent and the specific features of the images taken through a basic camera have been calculated very quickly in the computer environment. During the study, approximately 100 pieces of stone samples were provided and 80% of these samples were divided into two groups: training and 20% test data. Image processing based analysis method was applied to both groups and training data was used for calibration of the system. In the proposed approach, both image processing based analysis approach and laboratory crushing experiment were performed for each sample. As a result of all these tests, the proposed approach has been able to analyze the pressure strength on the stones with a margin of error of about 2%.

Keywords: *Image Processing, Artificial Neural Network, Compressive Strength, Stone.*

1. INTRODUCTION

There are many historical buildings in our country, which have reached daily from a wide variety of civilizations. Historical masonry structures are also among those structures that are regarded as cultural heritage. These historical buildings need to be transmitted safely to future generations. For this reason, it is necessary to examine these historic masonry structures in detail, to test the samples taken from these structures and to make the necessary actions according to the information obtained from these tests. At the beginning of these processes restoration process is coming. However, the mechanical properties of the materials used to accomplish this process need to be thoroughly examined [1]. At this point, the most important materials that make up the accumulation of stones are at the beginning of the stones.

There are a variety of methods used in the literature to determine the mechanical properties of natural stones used in masonry structures [2]. At the beginning of these mechanical properties is the compressive strength parameter [3]. Ultrasonic Pulse Velocity (UPV), Schmitt Hammer Rebound (SHR) methods and standard cubic samples were used in one of the studies carried out for this purpose in order to determine the uniaxial compressive strength of stones in pile structures. As a result of this study, a correlation between UPV method and standard cubic specimens was determined firstly, and it is proved that the method can be used in determining the uniaxial compressive strength [4]. In another study carried out on the subject, analytical and continuous sample methods were used to estimate the compressive strength of the masonry structures. It has been shown that the compressive strength of the structures decreases over time with these proposed methods [5]. In another study carried out on the subject of compressive strength, the compressive strength of concrete was measured. In this study, compressive strength of concrete was determined by image processing and artificial neural network methods. The compressive strength parameters of concrete structures conveyed to artificial neural networks were determined to process the information obtained from the concrete images taken through a camera [6]. In another study on concrete compressive strength, Baygin, et al. [7] performed measurement using image processing and artificial neural network techniques. For this purpose 100 samples have been provided and the images of these samples have been taken through a camera. From these images, standard deviation, arithmetic mean and median values were obtained by image processing. The obtained values were given to the artificial neural network and the system was trained. In the test procedures, the samples were divided into two groups as training and test group and the work was confirmed by laboratory tests. A block diagram of this work is shown in Fig. 1.

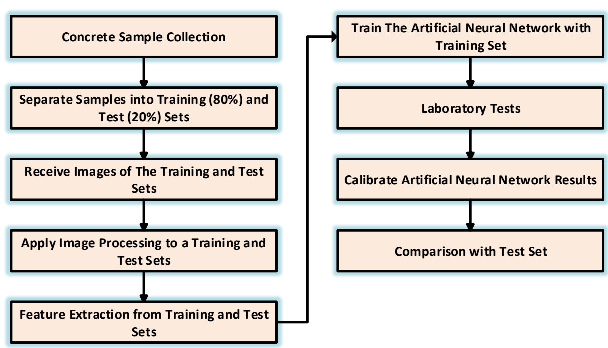


Fig. 1. An example study from the literature [7]

Image processing can be used in many different areas actively. In one of the studies performed in this frame, the detection of the rail surfaces was performed and a method for diagnosing the fault in the same operation was developed. In this work where the image processor is used, the failures between the rails have been determined with high success. Experimental results have proved that the proposed method gives accurate and effective results. In another study carried out on the compressive strength of concrete structures, the prediction of the concrete compressive strength using image processing was also carried out. In this frame, samples with different compressive strengths are produced in laboratory environment. Aggregate and cement percentages were obtained in the study and the compressive strength of the concrete was determined according to these values [8].

As mentioned in the beginning of the chapter, various methods have been developed in the literature in order to measure the compressive strength of constructions. These methods are grouped into destructive and non-destructive methods. Examples of destructive methods include buried sample and core sampling techniques. Examples of non-destructive methods are hardness tests, pull-out tests, penetration tests, mechanical sound wave velocity techniques and ultra sound velocity techniques [9].

In this work, a new method of measuring the compressive strength with image processing and artificial neural network has been developed. In this study carried out as an example of non-destructive methods, 2 different types of stone samples were used. In the experimental works carried out on a total of 100 samples (50 andesite stone, 50 tercan stone), the images of the stones were first taken via a camera and transferred to the computer environment. After this process, stones were crushed in the laboratory and the compressive strength values of the stones were obtained and documented. Image processing steps were applied to the stone images transferred to the computer environment and arithmetic mean, standard deviation and median values were extracted from this image. Finally, these data obtained in the system are given as input to the artificial neural networks and the compressive strength values of the stones are estimated. In the study, samples were divided into two groups, training and test group, and the tests were performed separately in both groups. As a result of this proposed method, it is observed that the compressive strength values of the stones used in the masonry structures can be detected with an error rate of + - 2%.

In the second part of this work carried out for this purpose, detailed features of the stone samples used in the system are presented. In the third part of the work, the proposed image processing based compressive strength technique is given in detail. In the fourth section, the results of the implementation are given and in the fifth and last section the results are shared.

2. STONE SAMPLES

In this study, two different types of natural stone extracted from the Eastern Anatolia Region of Turkey were examined. The stones examined in this study are Tercan stone (Erzincan, Turkey) and Andesite (Erzurum, Turkey). These stones, which are provided in the framework of the study, are tested in the laboratory and the compressive strengths of the stones are measured. Details of these stone samples with different compressive strength values are presented in sub-sections.

2.1 Andesite Stone

This stone type, which has a volcanic structure, can have gray, light or dark green, pinkish or light black colors depending on the minerals it contains. This stone type, which is very easy to remove and process, is concentrated in the Turkish region. A sample image of this stone used in laboratory experiments is as shown in Fig. 2.

Fig. 2. Andesite stone sample

2.2 Tercan Stone

This stone type, which is generally used as decoration material, has an easily removable and workable structure. Sample images of this stones, which have intensive reserves and are taken from the Erzincan region of Turkey, are as shown in Fig. 3.

Fig. 3. Tercan stone sample

3. PROPOSED APPROACH

In this study, a non-destructive method was applied to estimate the compressive strength using an artificial neural network based on image processing. With this method developed, the stones obtained in the study frame are taken through a camera and the process of breaking these stones is performed in the laboratory environment. A total of 100 specimen samples from different parts of Turkey were obtained and tested. A block diagram illustrating this work, which aims to measure the compressive strength parameter without the need for any laboratory testing, is presented in Figure 4.

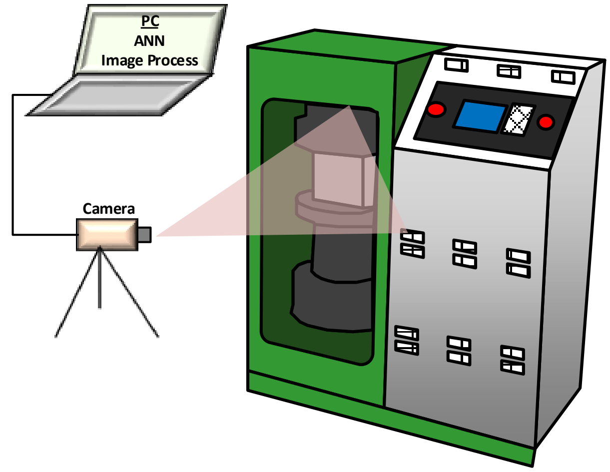


Fig. 4. Proposed approach

The samples used in the study belong to 2 different kinds of stones. These are Tercan and Andesite stone, respectively. As mentioned in the beginning of the chapter, the images taken in the scope of the study are examined with the help of an image processing algorithm and some information such as arithmetic mean, standard deviation and median are extracted from these images. These data are then given as input parameters to the artificial neural network and the compressive strength parameter is obtained as the output from this neural network. Artificial neural networks use train data as working principle. Example samples thus obtained are divided into training and testing groups. The designed artificial neural networks were firstly trained using the training set and later verified by the test set. 80% of each stone species was used as randomly as the training set was created. The remaining samples were used for the test set. In other words, each of the 50 sample groups was classified as 40 training and 10 test set. After the classification of these samples, each sample is subjected to the decomposition process in the laboratory environment. The system is calibrated at this point and the compressive strength for each specimen stone sample is obtained in MPa. After this, the trained artificial neural network is checked and verified with the test set. Finally, the results obtained from the test set are compared with the results obtained from the experiments performed in the laboratory and the process is completed. A flow diagram that summarizes all of these studies performed within the scope of the study is as given in Fig. 5.

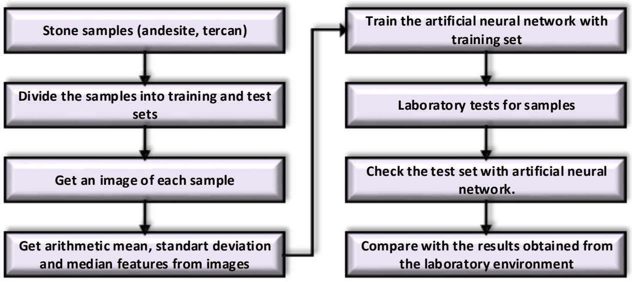
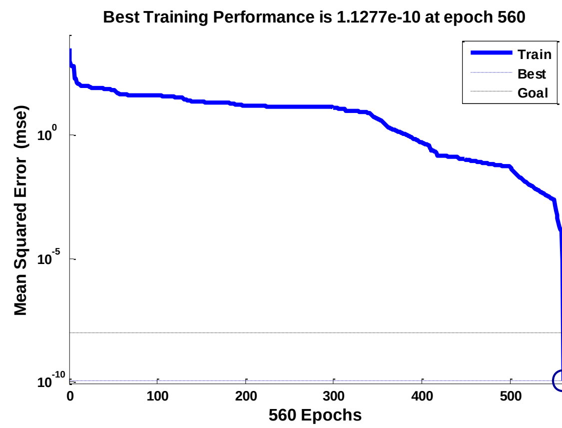


Fig. 5. A flowchart of the proposed approach

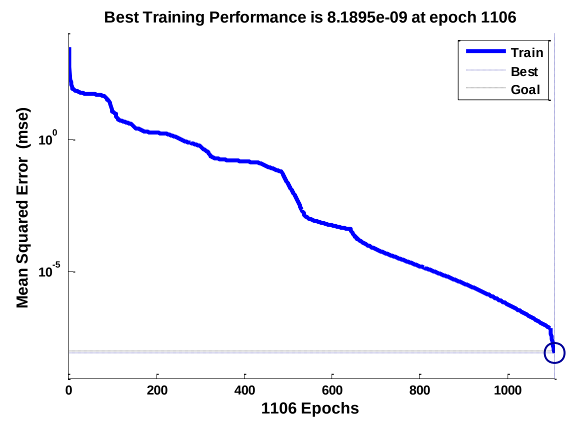
In the scope of the study, an artificial neural network with forward feed is designed. This designed artificial neural network has three inputs and one output. The input parameters of the system are the arithmetic mean, standard deviation and median, and the output parameter is the compressive strength. Details of this artificial neural network used during the study are as given in Table 1. In addition, a graphic showing the progress of the artificial neural network in the study process for all two sample types is presented in Fig. 6-(a) and (b) respectively.

Table 1: Artificial Neural network parameters

Parameters	***Values***
Type	Feed Forward
Input Layer	3
Output Layer	1
Hidden Layer	20
Learning Rate	$1xe^{-5}$
Goal	$1xe^{-8}$
Iteration	1000
Training Set	40 Andesite, 40 Tercan
Test Set	10 Andesite, 10 Tercan



(a) Andesite stone



(b) Tercan stone

Fig. 6. The progress of artificial neural network

4. EXPERIMENTAL RESULTS

In this study, a new method of using artificial neural network based on image processing for pressure bearing of stones was developed. Two different types of samples are provided for this purpose, and the pressure strengths of these samples are different. Basically one camera is used in the system to take an image of stone samples and subjected to certain pre-processes. In addition, these samples are investigated with the artificial neural network which is included in the system and designed within the scope of the study and the compressive strength values of the samples are determined. An image of the experimental setup used in the studies is as shown in Fig. 7.

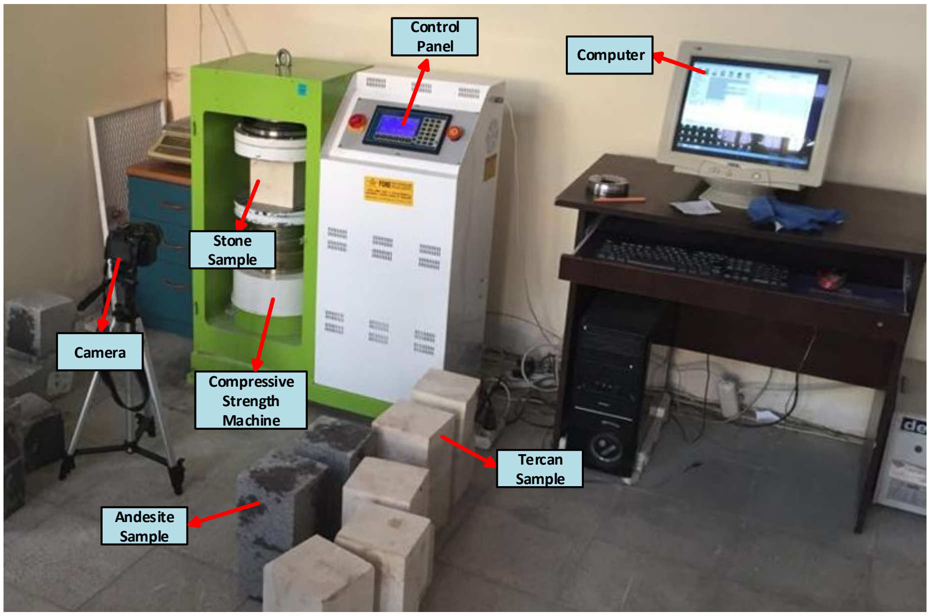


Fig. 7. Experimental setup

The arithmetic mean, standard deviations and median information of stones are extracted in image processing step and input to artificial neural networks. A total of 100 samples were used in the study, 50 for each of the two sample types. The values obtained for some of the samples used for training are as given in Table 2.

As given in the beginning of the section, only a certain part of the data used in the study is presented in this study. Sample values of the test samples used for this purpose are presented in Table 3. In addition, the compressive strength values obtained for test specimens are given in Table 4.

Table 2: Sample training data

	Parameters	Samples			
		Andesite Stone		Tercan Stone	
		S1	S2	S1	S2
Input	Standard Deviation	0.014	0.008	0.011	0.011
	Arithmetic Mean	0.366	0.362	0.554	0.543
	Median	0.380	0.376	0.584	0.592
Output	Compressive Strength (MPa)	53.09	41.24	13.43	15.02

Table 3: Artificial neural network parameters for test set

Samples	Input Parameters					
	Andesite Stone			Tercan Stone		
	Standard Deviation	Arithmetic Mean	Median	Standard Deviation	Arithmetic Mean	Median
S1	0.0146	0.4796	0.4980	0.0132	0.5718	0.6039
S2	0.0153	0.2874	0.2824	0.0096	0.5350	0.5725
S3	0.0119	0.4139	0.4314	0.0080	0.5219	0.5569
S4	0.0099	0.4065	0.4157	0.0121	0.5372	0.5725
S5	0.0127	0.3955	0.4157	0.0259	0.6925	0.7098
S6	0.0200	0.3822	0.4000	0.0210	0.6131	0.6294
S7	0.0122	0.3802	0.3961	0.0197	0.5437	0.5882
S8	0.0136	0.4424	0.4588	0.0248	0.5900	0.6039
S9	0.0143	0.4598	0.4745	0.0329	0.5957	0.6118
S10	0.0136	0.4730	0.4863	0.0302	0.6301	0.6471

Table 4: Test results obtained from laboratory environment and artificial neural network

Samples	Test Results (MPa)					
	Andesite Stone			Tercan Stone		
	Laboratory Test (LT)	Prediction Values (PV)	LT/PV	Laboratory Test (LT)	Prediction Values (PV)	LT/PV
S1	32.1820	25.7456	1.250	17.6360	18.7236	0.941
S2	59.8250	58.4312	1.023	23.0930	22.1410	1.042
S3	58.2760	56.5342	1.030	12.9240	13.5471	0.954
S4	55.5820	55.2310	1.006	19.2670	18.9856	1.014
S5	65.5870	68.6241	0.955	17.7910	16.9701	1.048
S6	67.6490	66.6278	1.015	15.6440	15.5213	1.007
S7	35.9560	35.2377	1.020	18.4310	17.4220	1.057
S8	33.1470	34.6540	0.956	16.6440	15.7329	1.057
S9	38.3070	38.7536	0.988	19.7420	19.6312	1.005
S10	63.8400	63.7223	1.001	18.1160	19.8645	0.911
		Total	10.2493		**Total**	10.0435
		Ratio	1.025		**Ratio**	1.004

As can be seen from Table 4, as a result of this study, a comparison of the compressive strength values with the laboratory tests resulted in a margin of error of +-2%. However, the compressive strength values of the stones can be obtained as MPa without any laboratory tests.

5. CONCLUSIONS

In this study, a new method of predicting compressive strength using image processing and artificial neural network is proposed. Tests for two different types of stone specimens were carried out within the framework of the studies. The proposed approach was carried out in two stages. In the first stage, images taken through a camera were subjected to necessary pre-processing and predicted by using artificial neural network. In the second stage, laboratory tests were carried out to obtain the actual compressive strength values of the stone samples and the system was calibrated. Finally, the software and laboratory compressive strength values obtained from the test images were compared and it was determined that the system works with an error margin of +-2%. This approach, which can be shown as an example of non-destructive measurement methods, has created a system which is quite cost effective, advantageous in time and can give a smooth result.

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